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16. Abstract

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Major activities described in this document include development and evaluation of theoretical models that describe both active and passive microwave sensing of soil moisture, the evaluation of these models for their applicability, the execution of a controlled field experiment during which passive microwave measurements were acquired to validate these models, and evaluation of previously acquired aircraft microwave measurements. The document also describes the development of a root zone soil water and soil temperature profile model, calibration and evaluation of gamma ray attenuation probes for measuring soil moisture profiles, and a brief discussion of the analysis of spatial variability of soil information as related to remote sensing. The final major activity described in the document is the implementation of an instrumented field site for acquisition of soil moisture and meteorologic information for use in validating the soil water profile and soil temperature profile models.

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INTERIM REPORT

# INVESTIGATION OF REMOTE SENSING TECHNIQUES OF MEASURING SOIL MOISTURE


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This report describes activity carried out in support of the Soil Moisture Research activities of the Project.


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## ABSTRACT

This report summarizes the activities under NASA Grant NAG 5-31 for the period from March 1, 1980 to January 31, 1981. The primary objective of the research reported in this document is to develop a technique of remotely estimating a soil water parameter as a function of soil depth and areal coverage. A multi-disciplined team was organized to address this research effort. As such, the project was divided into three coordinated tasks: application of microwave sensor systems to estimating soil moisture, root zone soil water algorithm development, and controlled field experiment. This report summarizes efforts that are documented in formal technical reports as well as activities that were not completed during this funding period and those that were not documented in formal reports. Those activities that were not completed during this funding period will be completed during the following funding period and will be documented in formal reports at that time.

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brief discussion of the analysis of spatial veriability of soil information as related to remote sensing. The final major activity described in the document is the implementation of an instrumented field site for acquisition of soil moisture and meteorologic information for use in validating the soil water profile and soil temperature profile models.

# INVESTIGATION OF REMOTE SENSING TECHNIQUES FOR MEASURING SOIL MOISTURE

## NASA Grant NAG 5-31

## INTRODUCTION

The research described in this document is a continuation of the major activities that were in progress under funding from NASA contract NAS 9-13904. The work under that contract is summarized in Final Report RSC-3058 [1]. The primary objective of this research is to develop a technique of remotely estimating a soil water parameter as a function of soil depth and aerial coverage. As a result of contract NAS 9-13904, it was determined that the major steps involved in fulfilling the objective of this project are the development and verification of an approach to remotely sense a near surface soil water parameter, the development of a hydrologic model that will estimate soil water at root zone depths utilizing the near surface soil water estimates, and the extension of these techniques to large areas. A multi-discipline team was organized to address this research effort. As such, the project was divided into three coordinated tasks: application of microwave sensor systems to estimating soil moisture, root zone soil water algorith development, and controlled field experiment. Dr. R. W. Newton, Dr. L. Tsang, and Dr. A. J. Blanchard addressed the first activity area, Dr. C. H. M. van Bavel the second, and Dr. J. L. Nieber the third.

This report will summarize the activity during the first year of funding. Several published technical reports are attached to this document describing activities that were completed during this grant period. Several activities that were ongoing and not completed at the end of this grant year and, therefore, not published as stand alone technical reports are documented in the body of the text below. All of this material has been presented in an oral report given at the Annual Integrated Soil Moisture Working Group meeting held March 18-20, 1981 at the U. S. Department of Agriculture Research Center in Beltsville, Maryland. A brief six month report was sent to the Technical Monitor September 30, 1980 describing the research accomplishments that had been made up to that point in time. This report is contained in Appendix A. In addition, major results and planned activities for the time period through December 1980 were documented in a memorandum as input into the Integrated Soil Moisture Program peer review presentation. This memorandum is contained in Appendix B.

In the three major sections below, the research involved in the three activity areas are described. Technical Reports that have been completed during the contract period are referenced and attached to this document. The status of other activities that have not been completed are also described.

# INTERPRETATION OF ELECTROMAGNETIC MEASUREMENTS FROM AGRICULTURAL SCENES

The following section documents activities under the direction of Drs. R. W. Newton, A. J. Blanchard and L. Tsang. This section is divided into three major divisions: Evaluation of Models and Experimental Results, Active Microwave Measurements and System Constraints, and Microwave Scattering and Emission Theory. Some of the activities descibed in this section are documented in Technical Report RSC-107 (AgRISTARS report SM-T2-04366), Technical Report RSC-108 (AgRISTARS report SM-T1-40457), Technical Report RSC-110 (AgRISTARS report SM-T1-20458), and Technical Report RSC-122 (AgRISTARS report SM-T1-04152). Activities that are not detailed in formal technical reports were not completed during this funding period and will be formally reported in the next funding period.

## Evaluation of Models and Experimental Results

### Model Evaluation

Technical Report RSC-108 (AgRISTARS report SM-T1-40457) documents a study completed by Black and Newton concerning the utilization of theoretical models of microwave emission from moist soil to identify differences between coherent and incoherent models, develop an understanding of the depth of penetration of microwave emission measurements, and compare theoretical calculations with experimental microwave measurements. This report is contained in the Attachment to this document. The theoretical study described in Technical Report RSC-108 was undertaken to address unanswered questions related to the adequacy of coherent vs incoherent radiative transfer theory to describe microwave emission from soil and the depth to which soil moisture can be estimated. The effect of the arbitrary selection of near surface soil layer thickness on results obtained with coherent and incoherent radiation transfer models is discussed. It was determined that both types of models adequately predict experimental measurements when near surface layers are defined properly. In addition, it is shown that the modulation of soil brightness temperature by the surface soil layer is so strong that it precludes direct measurement of soil moisture below two to five centimeters. This is true even though significant portions of the emitted microwave energy originates at greater depths, up to 20 centimeters. Comparison of the depth of penetration computed using both coherent and incoherent models show that the coherency assumption does not significantly affect computed contribution depth. In all cases tested, the difference between coherent and incoherent percent contribution depth was never more than a centimeter. Furthermore, surface incident angles do not appreciably affect penetration depth, confirming the results of Wilheit [1] and Newton [2].

It was determined that the EQSM sampling depth as defined by Newton [2] corresponds to the soil depth above which 90% of the thermal microwave emission originates. Since the EQSM represents the average moisture to the 90% contribution depth, and the EQSM parameter does correlate to brightness temperature measurements, information about soil moisture at depths greater than a tenth of a wavelength is obviously contained in the microwave emission measurements. This does not necessarily mean, however, that the moisture information is related directly to the microwave measurement. It is possible that "deep" soil moisture information is available only because there is a strong correlation between near surface soil moisture (approximatley 0-2 cm) and deeper soil moisture.

It was determined by computing microwave emissivities using soil moisture and soil temperature profiles measured by Jackson [3] in Tempe, Arizona in 1971, that the 0-1 centimeter soil moisture had a more direct correlation to microwave emissivity than did the EQSM parameter or average soil moisture within any other surface layer. This statement is made since the microwave emissivity versus the 0-1 centimeter soil moisture curve most closely resembles the variation of the transmission coefficient of an air soil interface where the soil contains a uniform soil moisture. It was also determined that the EQSM parameter corresponded most closely to the 0-20 centimeter soil moisture average.

The results of Black and Newton in Technical Report RSC-108 suggest that the brightness temperature generated by the model is dominated by the air soil transmission coefficient. It can be seen in the equation for the EQSM parameter that the parameter is independent of the air soil transmission coefficient due to the ratioing effect of the brightness temperature at each depth with the total brightness temperature. In addition, the thermal sampling depth as defined by Wilheit [1] is independent of the air soil transmission coefficient although the reflectivity sampling depth is not. It should be noted that the EQSM sampling depths and the thermal sampling depths are very similar and much deeper than the reflectivity sampling depth.

The effect of the air soil transmission coefficient can be seen clearly in Figure 1 where both the brightness temperature computed just above the soil surface (including the air soil transmission coefficient) and the brightness temperature computed just below the surface are both plotted as a function of EQSM. It can be seen that the brightness temperature just above the soil surface is strongly dependent on soil moisture, while the brightness temperature just below the soil surface is only weakly dependent on soil moisture changes. This figure clearly shows the dominance of the air soil interface transmission coefficient on overall soil emission. Since the EQSM parameter is not dependent on the air soil transmission coefficient, microwave measurements directly correlate to it in a weak fashion. The strong correlation observed experimentally [2] is apparently due to the correlation of subsurface soil moisture to surface soil moisture.

### Evaluation of Aircraft Measurements

Technical Report RSC-108 also describes an airborne experimental measurement program that includes several large scale experiments implemented at different locations around the U.S. L-band data from these experiments demonstrate the feasibility of measuring soil moisture with airborne microwave radiometers. Measurements of bare fields are used to show that the optimum moisture estimation parameter in terms of estimation accuracy is simply the 0-2 cm average soil moisture. Microwave emissivity is shown to have no advantage over microwave antenna temperature as a radiometer measurement parameter

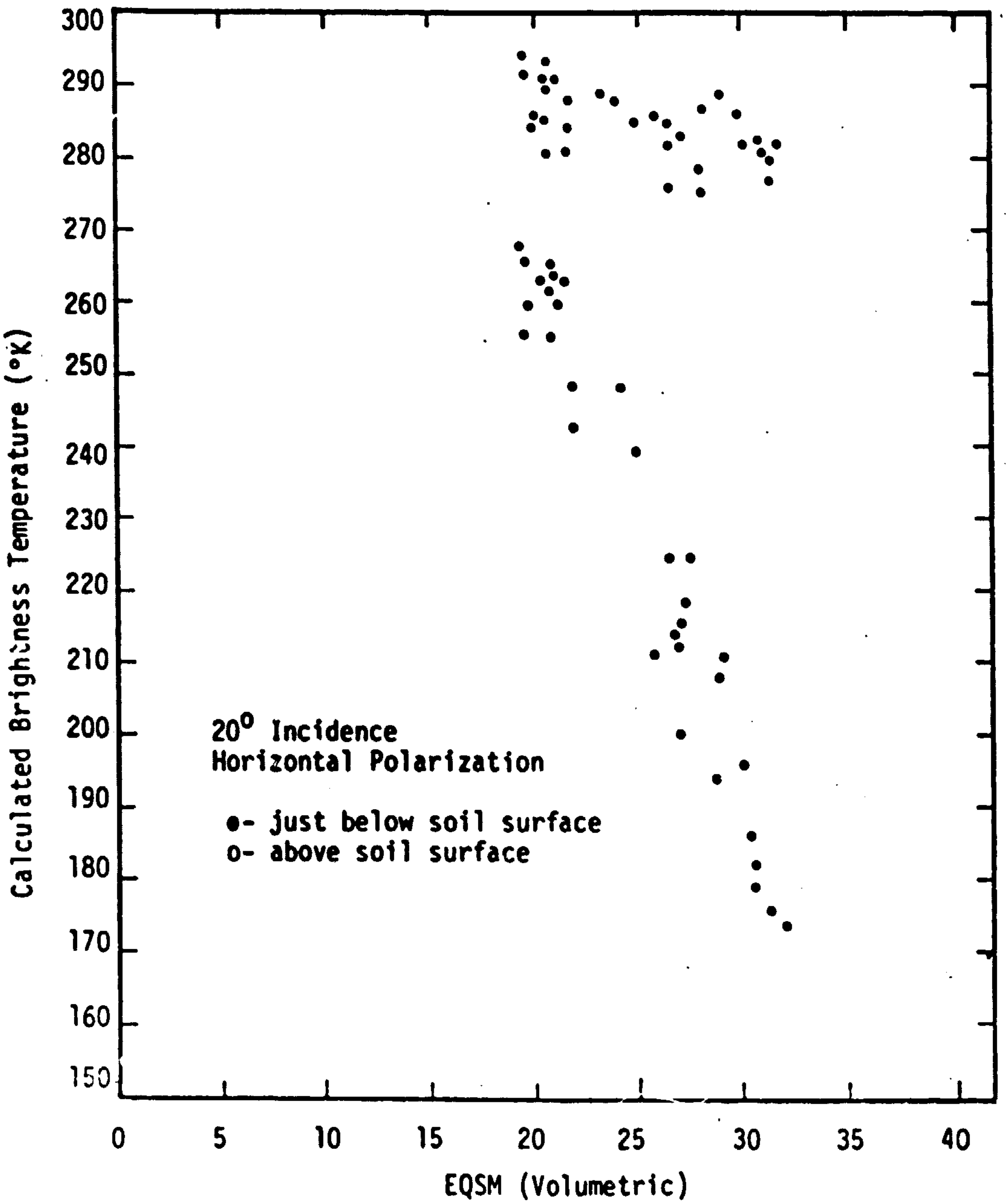


Figure 1. Calculated 1.4 GHz microwave brightness temperatures plotted against equivalent incoherent soil temperature

' r the data used. This is probably due to a lack of seasonal temperature variation between the different experiments, and measurement uncertainty in the soil temperature measurements aquired as ground truth. It is also concluded that there is generally good agreement between airborne measurements, truck measurements, and emission theory with regard to the relationship between microwave emission and soil moisture. However, discrepancies exist between the moisture sensitivities of small scene and large scene radiometer measurements of vegetated fields. The vegetation data that currently exist are not extensive enough to resolve these discrepancies. A more extensive program of vegetation measurements as proposed.

**Experimental Truck Radiometer Measurements**

Between June 30, 1980 and July 30, 1980 an extensive passive ground based microwave soil moisture experiment was executed at Texas A&M University Research Farms in Brazos Valley. The purpose of the experiment was to obtain passive microwave data at 1.4 GHz, 4.9 GHz and 10.7 GHz at vertical and horizontal polarization for incident angles from nadir to 50° simultaneously with ground truth measurements of well controlled agricultural fields to demonstrate the dependence of the received microwave radiation on soil moisture, soil temperature, surface roughness, and vegetation cover. Eight fields were used in the experiment, three of which were prepared with a row tilled surface and had sorghum planted in them. The remaining fields were bare and prepared with uniform surface roughness ranging from very smooth to very rough. Technical Report RSC-122 (AgRISTARS report SM-T1-04152) documents the reduced ground truth that was acquired during this experiment. This report is contained in the Attachment to this document. Preliminary results of the analysis of the microwave measurement acquired during this experiment are presented below.

## Selected Results of the 1980 Summer Experiment

**Depth of Penetration** - It is difficult to demonstrate the depths to which microwave radiometers can measure moisture directly. One method to experimentally demonstrate the penetration depth is by obtaining microwave emission measurements over bare soil acquired as a function of time during soil dry down from saturation to the dry state with no water input events during this dry down period. The brightness temperature measurements can be converted to an estimated soil moisture and the dry down curve of the estimated soil moisture compared to the dry down curves for the average soil moisture in various depth intervals. The penetration depth at any time can be obtained by observing the soil moisture average to which the estimated soil moisture corresponds at any point during the dry down period.

The 1980 field experiment described above had the conditions required. In this experiment, four bare fields were measured from saturation through dry down. These fields ranged in roughness from smooth to very rough. Since Texas experienced a severe drought condition during the experiment, no rainfall occurred during the experiment. Figure 2 shows the soil moisture of the smooth field for three depth increments, 0-2 centimenters, 0-5 centimeters, and 0-9 centimeters as a function of time from soil saturation to soil dry

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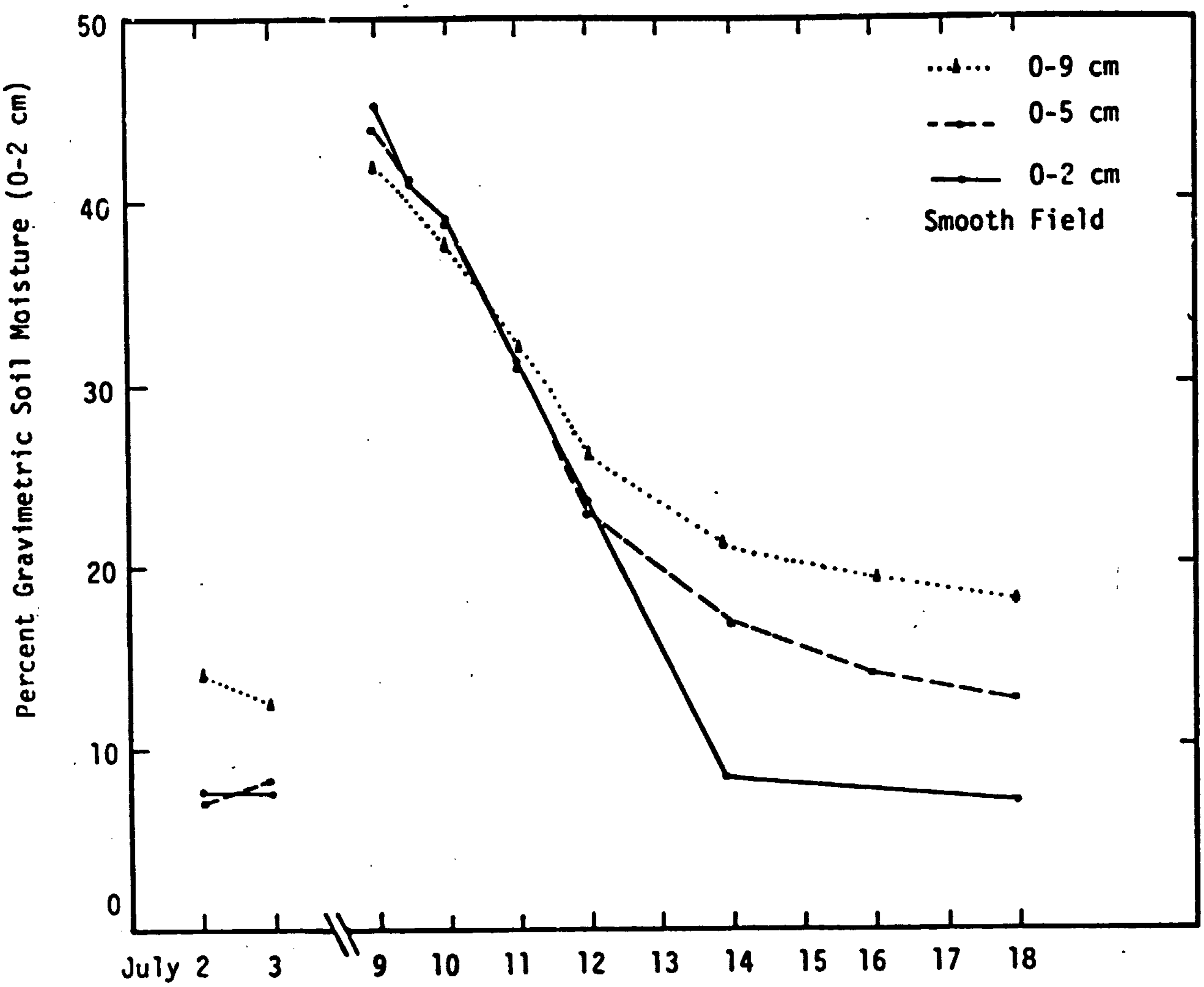


Figure 2. Dry down curves for three soil layers in the smooth field.

down. It can be seen that the soil moisture at the deeper depth intervals dry out much more slowly than the shallower depth intervals.

The microwave brightness temperature measurements for the smooth field were used to compute an estimated soil moisture. These estimates were also plotted as a function of time in Figure 3. The soil depths to which the microwave measurements correspond can be obtained by comparing the dry down curve for the estimated soil moisture to the dry down curve for the various depth intervals. It can be seen in Figure 3 that these estimated soil moisture dry down curves correspond very closely to the dry down curves for the 0-2 cm or shallower soil moisture in Figure 2. This result supports the contention of Schmugge, et al. [4] that only soil moisture in the very near surface can be measured directly. Figure 3 also demonstrates that the depth of penetration is frequency dependent since the estimated soil moistures dry down more slowly as the wavelength gets longer. The data presented in Figures 2 and 3 are the only data currently available from which such analysis can be done. The results support the theoretical prediction of Wilheit [1] concerning the effective reflectivity sampling depths.

Surface Roughness - A thorough analysis of experimental data was done by Newton [2] to demonstrate the effect of uniform surface roughness on microwave brightness temperature measurements of bare soil. It was demonstrated that as roughness increases the microwave brightness temperature also increases and the sensitivity of the brightness temperature to soil moisture decreases. Newton reported only measurements at 1.4 GHz and 10.7 GHz. At these two frequencies

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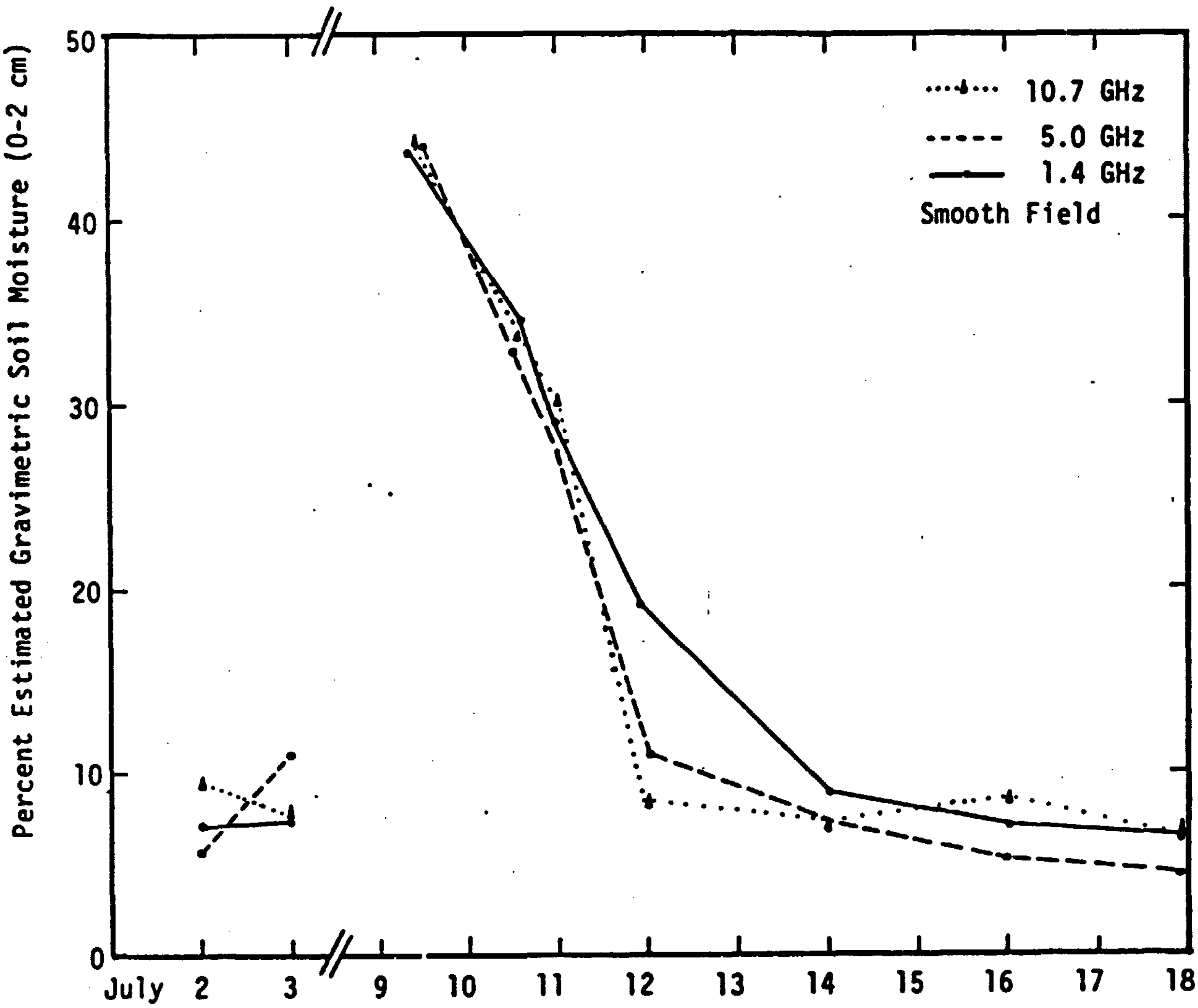


Figure 3. Percent soil moisture versus time estimated from 1.4 GHz, 5.0 GHz, and 10.7 GHz measurements of the smooth field.

it was demonstrated that there was a wavelength dependence on surface roughness whereby the shorter the wavelength the rougher the surface appeared. At 1.4 GHz the microwave brightness temperature sensitivity to soil moisture decreased from -4.9°K/percent soil moisture (0-2 cm) for an rms surface height of .88 centimeters to -1.9°K/percent soil moisture (0-2 cm) for an rms surface height of 4.2 centimeters.

Based on previous results of Newton [2], it was predicted that the effect of surface roughness on microwave brightness temperature measurements at 5 GHz would fall between the effects seen at 1.4 GHz and 10.7 GHz. However, the results reported by Ulaby and Batlivala [5] for active microwave measurements on bare soil surfaces were that the effect of surface roughness was minimized at 5 GHz. Data were acquired at the Texas A&M University Research Farms during the summer of 1980 for bare soil surfaces ranging from very smooth to very rough. These measurements were acquired at 1.4 GHz, 5 GHz, and 10.7 GHz. Figures 4, 5 and 6 illustrate the effects of surface roughness at 1.4 GHz, 5 GHz, and 10.7 GHz respectively. Figure 7 illustrates the effect of frequency on the effective surface roughness of the soil.

Figures 4, 5 and 6 demonstrate that surface roughness has a measureable effect at frequencies from 1.4 GHz to 10.7 GHz . The results at 1.4 GHz and 10.7 GHz corroborate the results obtained by Newton [2] using microwave radiometer measurements acquired in 1974 at the Texas A&M University Research Farms. It is apparent from comparing Figures 4, 5 and 6 that a given surface roughness has a different effective roughness for each frequency. This is better illustrated in Figure 7 where measurements at 1.4 GHz, 5 GHz, and 10.7 GHz

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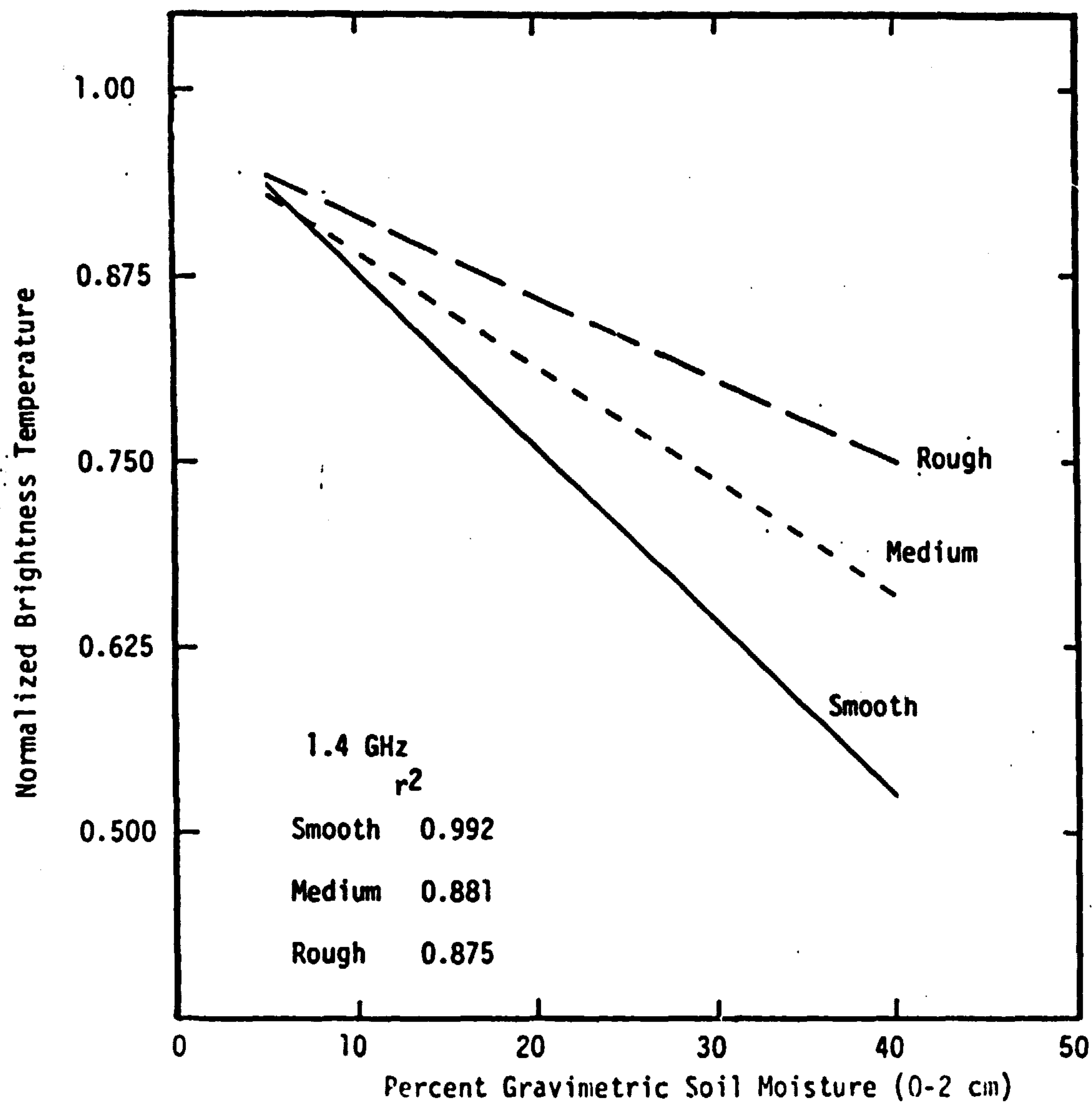


Figure 4. Best linear fits of the 1.4 GHz measurements of bare soil for three surface conditions

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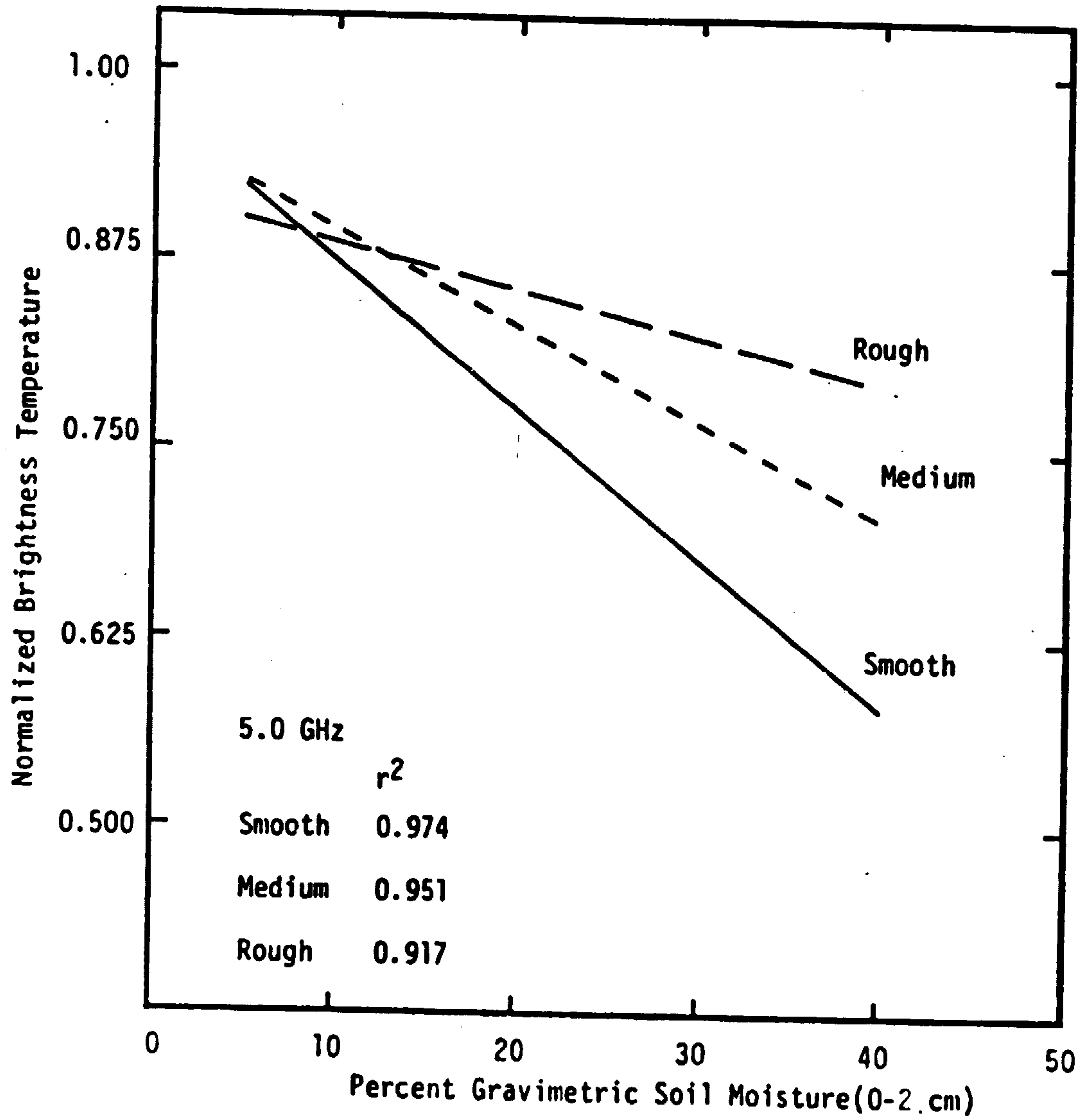


Figure 5. Best linear fits of the 5.0 GHz measurements of bare soil for three surface conditions.

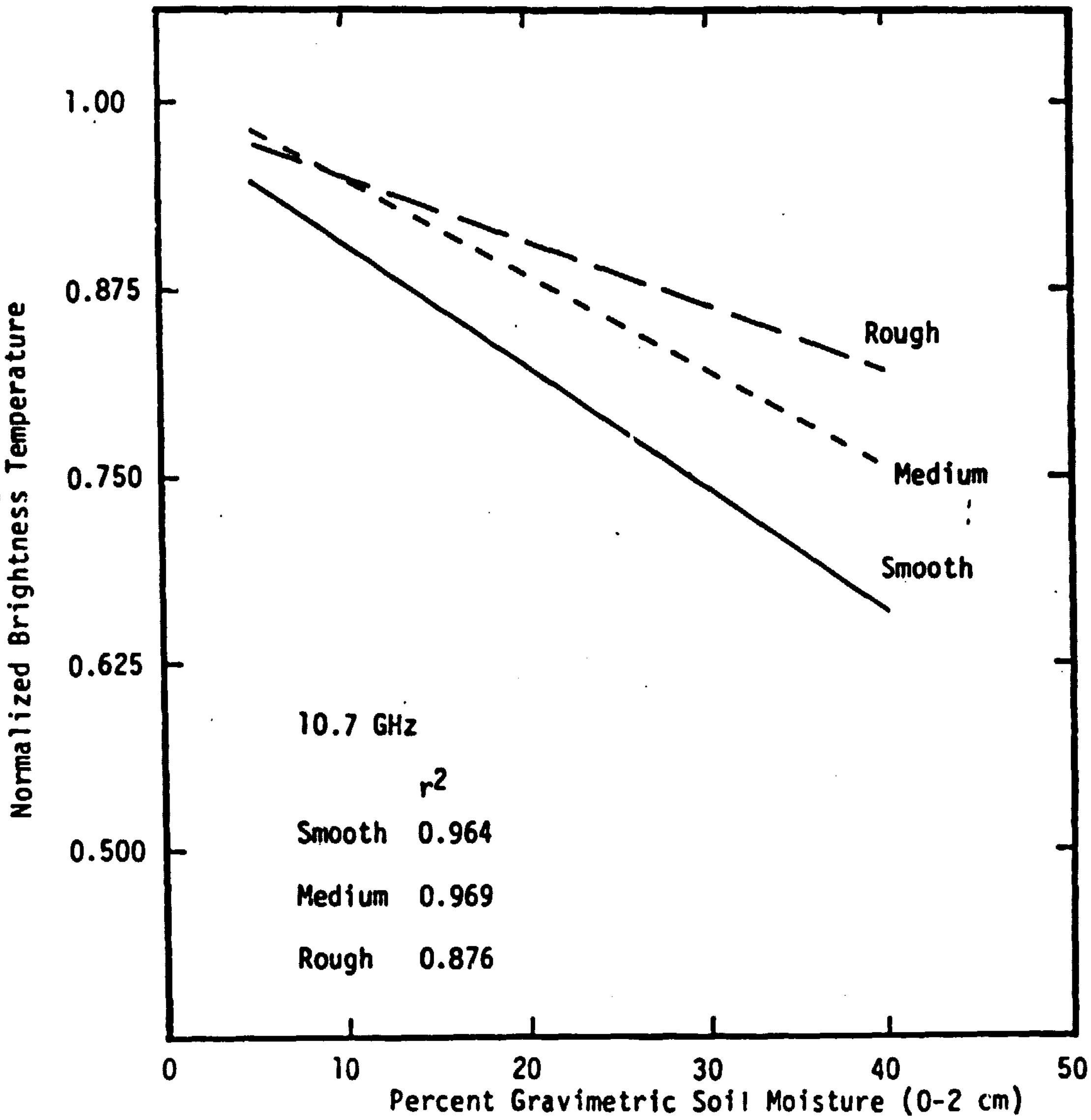


Figure 6. Best linear fit of the 10.7 GHz measurements of bare soil for three surface conditions.

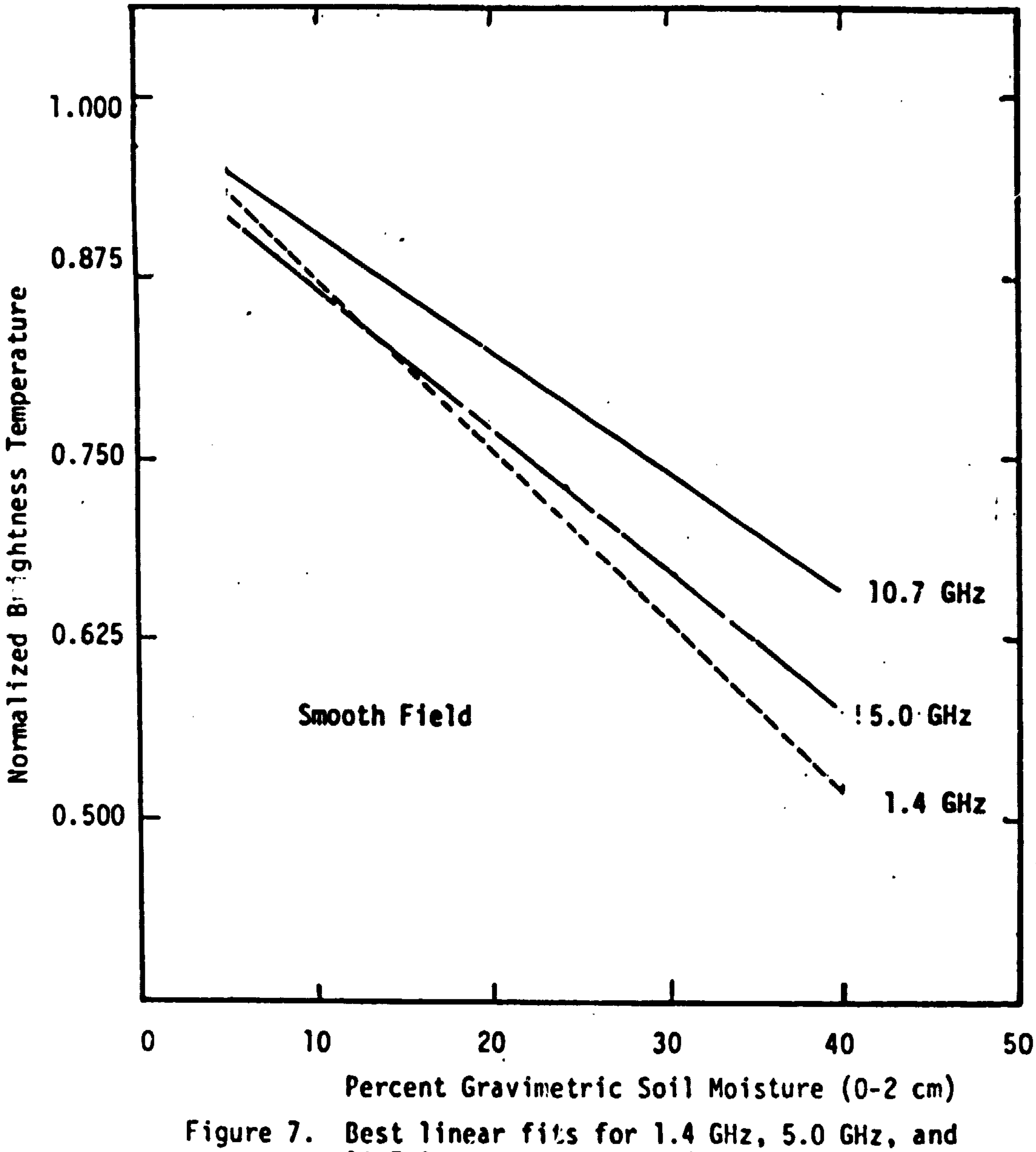


Figure 7. Best linear fits for 1.4 GHz, 5.0 GHz, and 10.7 GHz measurements of the smooth bare field.

are all plotted for the smooth field. It is apparent that even the smooth field appeared rougher at 10.7 GHz than at 5 GHz, and rougher at 5 GHz than at 1.4 GHz. This result confirms Newton's [4] expectation that 5 GHz measurements would be affected by surface roughness in a similar fashion to 1.4 GHz and 10.7 GHz measurements. Figure 8 is a plot of the slope of the best fit lines contained in Figures 4, 5, and 6 for each frequency and each surface roughness. The slope corresponds to the sensitivity of the microwave radiometer response to soil moisture. Figure 8 summarizes the results of Figures 4, 5, and 6, again demonstrating the shorter the wavelength the rougher the surface appears, and that 5 GHz measurements do not minimize the roughness effect for passive microwave measurements.

## Active Microwave Measurements and System Constraints

### Volumetric Effects in Cross-Polarized Radar Measurements

In the past ten years much theoretical and experimental work has been done to identify the sensitivity of microwave backscatter data to soil moisture. Microwave backscatter is dependent upon the geometry and the electrical characteristics of the target. Target geometry includes both surface roughness and discontinuities that exist within the volume. The electrical characteristics are expressed in terms of the complex permittivity of the subsurface. Theoretical and experimental attempts have been made to unravel the dependence of the backscatter upon these geometrical and electrical parameters. Specifically, interest has been directed toward theoretically determining the response of the backscatter to roughness as a function of inci-

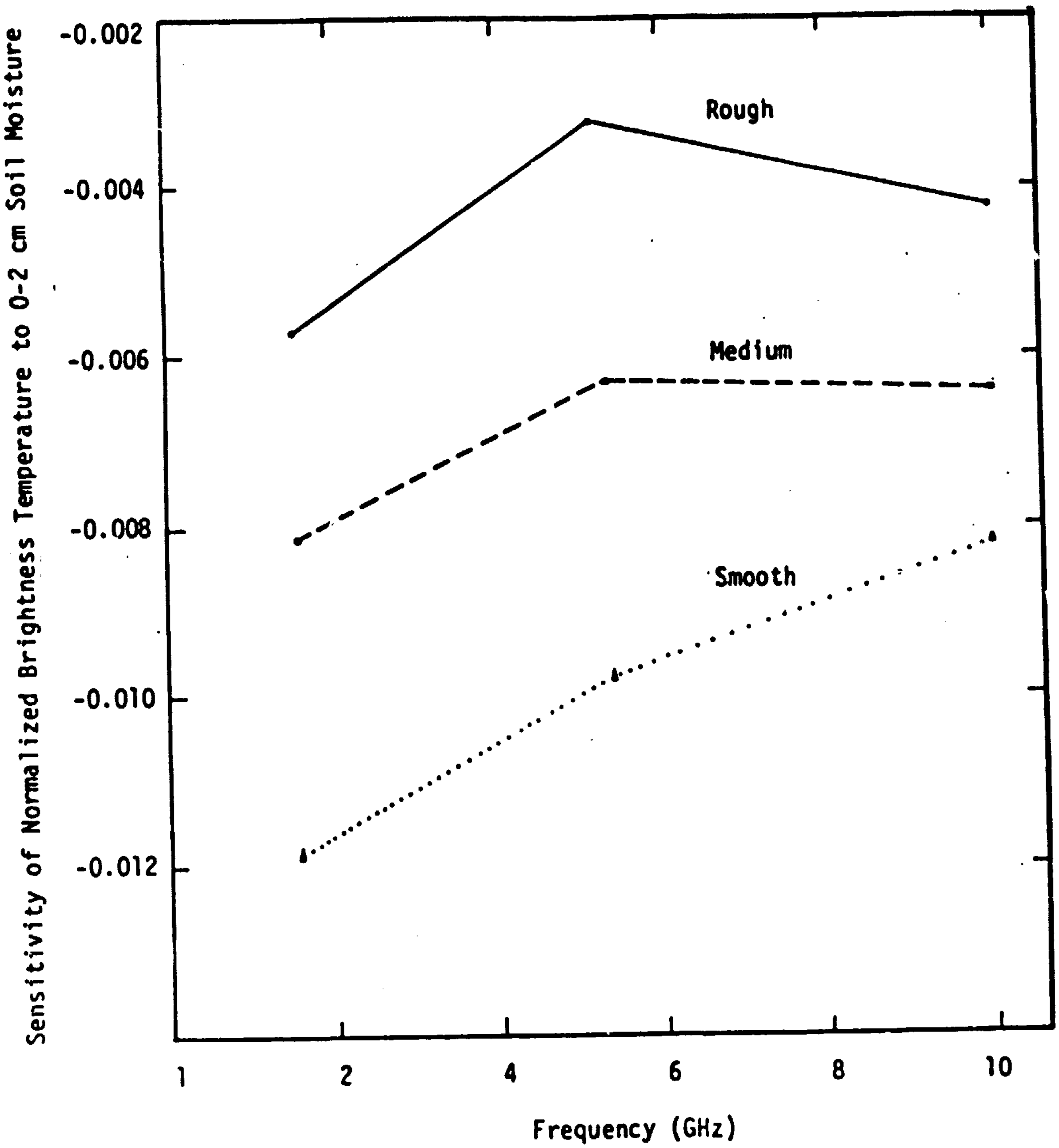


Figure 8. Slope of the best fit lines to the 1.4 GHz, 5.0 GHz, and 10.7 GHz measurements to soil moisture for all three surface conditions.

dent angle and to soil moisture as a function of incident angle and frequency.

There are two issues of concern. First, the sensitivity of backscatter to soil moisture as a function of incident angle and secondly, the sensitivity of the cross polarized radar return to surface roughness. Analysis of the first issue indicates that a volumetric effect contributes to the decrease in the sensitivity of radar backscatter to soil moisture as a function of incident angle. From this analysis, the conclusion is that the volume contribution is significant. The volume backscatter model used in this analysis predicts depolarized cross sections which are a function of properties of the volume. This model predicts depolarized cross sections which are independent of surface roughness. This result is significant in that the theory predicts that we are capable of making a volume dependent measurement (soil moisture) independent of surface effects.

**Antenna Effects in Depolarization Measurements**

The depolarization of the electromagnetic energy scattered from natural terrain has been of interest to experimentors and theoreticians for many years. However, the reported measurements have not agreed with theoretically predicted results. Boresite axial ratio has commonly been used as a figure of merit to describe the polarization isolation properties of antennas. Since depolarization measurements from terrain involves extended targets that fill the antenna beam, boresight axial ratio is often an inadequate measure of the polarization purity of an antenna.

Recent investigations have shown the need for more stringient isolation requirements between the like and cross polarized antenna channels in making depolarization measurements. Dish antenna systems characteristically have side lobe isolation values which are much less than the boresight isolation. Computations are being performed to demonstrate the antenna isolation characteristics that impact the quality of the depolarized measurements. A criteria for antenna characteristics is being computed which will guarantee high quality cross polarized measurements.

### Radar Construction

In order to address the issue of quality of depolarization measurements, a truck mounted radar system is being constructed although currently unfunded by this grant. The radar system is being designed specifically to make accurate cross polarized measurements. The system will consist of three radar heads with center frequencies at 1.6 GHz, 4.75 GHz, and 10.0 GHz, all using a common 60 MHz IF receiver. Pulse compression techniques will be used to obtain adequate range resolution. The antennas will be optimized to insure adequate polarization isolation across the beamwidth. The entire system will be automated under computer control.

## Microwave Scattering and Emission Theory

The four activities briefly summarized below, were initiated during this funding period. The first two are documented in Technical Report RSC-107 (AgRISTARS Report SM-T2-04366) and Technical

Report RSC-110 (AgRISTARS Report SM-T1-20458), both of which are attached to this document. The remaining two were not completed to the point that a formal technical report or publication could be written documenting the efforts. These research topics will be continued during the next funding period and publications concerning their results will be generated at that time.

**Scattering of Electromagnetic Waves by Random Medium with Strong Permittivity Fluctuation**

All previous random media theories that have been applied to microwave remote sensing applications are only valid for the case of weak fluctuations of dielectric constant. By taking into proper account the singularity of the dyadic Green's function and the renormalization method, vector electromagnetic wave scattering from random medium with large variance of the permittivity function is studied. The strong fluctuation theory distinguishes between internal and external fields. The results of the strong fluctuation theory are consistent with those derived from discrete scatterer theory for all values of dielectric constants of the scatterers. The results are applicable to scattering and vegetation layers of soils.

**Microwave Emission from Soils with Rough Interfaces**

The effect of surface roughness on brightness temperture of soils has been studied with a Kirchoff approach. The model incorporates both the coherent and incoherent reflectivities of the rough surface. The theoretical model indicates that, for wet soil, the roughness of the surface will cause an increase in brightness temperature, and is in good agreement with the experimental data. In matching data collected from field measurements, the physical height of the rough surface is used rather than an effective height. The significance of this model is that it can use physically measurably surface roughness parameters and predict a brightening effect of rough surfaces as seen in experimental measurements.

### Radiative Transfer Theory for Active Sensing of Vegetation

The radiative transfer theory is applied to calculate the back-scattering cross-section of a layer of randomly positioned and oriented small elipsoids. The orientation of the elipsoids is characterized by a probability density function of the Eulerian angles of rotation. In the half space limit, the results are identical to those obtained via the approach of Foldy's and distorted Born approximation. The numerical results of the theory are illustrated using parameters encountered in active remote sensing of vegetation layers.

### An Approximate Relation Between Active and Passive Microwave Remote Sensing Measurements

Based on the fact that volume scattering is relatively omnidirectional, a simple approximate relation is derived between active and passive microwave remote sensing measurements for earth terrain where volume scattering plays a dominant role. The relation gives an estimate of the backscattering coefficient from the emissivity measurements and visa versa. It is useful in checking experimental measurements and verifying the validity of theoretical models.

## ROOT ZONE SOIL WATER ALGORITHM DEVELOPMENT

The activities described in this section represent the participation of the Department of Soil and Crop Sciences in this program. Dr. C. H. M. van Bavel is responsible for the activity as Co-investigator and was assisted by three additional individuals. Their activities focused in three areas: a) improvement and adaption of techniques for measurement of soil water content, and of surface albedo and emittance; b) improvement in adaption of a hydro-energetic model to predit soil water concent and soil temperature profiles as a function of time, meteorological events, and soils characteristics; and c) analysis of spatial variability and its implications for sampling, measurement, and interpretation of both ground and remote measurements. These activities have been documented in formal technical reports that are attached to this document. These reports are: Technical Report RSC-113 (AgRISTARS Report SM-T1-04060), Technical Report RSC-112 (AgRISTARS Report SM-T1-40463), Technical Report RSC-111 (AgRISTARS Report SM-T1-04059),and Technical Report RSC-134. Copies of each of these reports are attached to this document.

### Soil Water Content Profiles From Gamma Attenuation

In 1980 two Troxler gamma-ray attenuation probes, one of which had been calibrated in the laboratory in 1978, were used to (a) establish the dry bulk density profile at each of 26 measurement sites in a set of plots used for microwave emission studies, and (b) to determine the volumetric water content profiles during a 44-day period thereafter. The latter measurements were made by personnel from

Agricultural Engineering, as the site operators. The results were used to determine the reproduceability of the equipment in a demanding environment (air temperatures above 40°C at times) and of the differences, if any, between the two probes and between different operators.

The laboratory calibration established the numerical coefficients in the equation

$$I = I_0 \exp(d_s m_s + d_w m_w)$$

in which I is the observed count rate in counts per second (cps) and $d_s$ and $d_w$, the dry bulk density and the volumetric water content, respectively. The constants are

$I_0$ - the count rate in air, found as 4453 cps

$m_s$ - the soil attenuation factor, found as 2.181 $cm^3/g$

$m_w$ - the water attentuation factor, found as 1.643

For the second probe, the values of $m_s$ and $m_w$ were assumed to be identical, but the value for $I_0$ was measured and found as 5071 cps. The $I_0$ values are calculated for July 1, 1980.

Once the dry bulk density profile has been established, all water content values are found from

$$d_w = (\ln(I_0/I) - d_s m_s)/m_w$$

With an aid of a hand-held programmable calculator, the water content profile can be calculated in the field, while measurements of I are obtained.

The results obtained over a two-month period showed that (a) the temperature compensation of the equipment was well within the statistical error of counting, (b) the difference between the two instruments was likewise not significant, and (c) the difference between repeated measurements was not significant, but some operators had noticeably better results than others.

As an example, Figure 9 shows how closely the dry bulk density profile of an area, characterized by 4 sites, is defined. Generally, it is quite impossible to obtain this information for the top 5 cm with any degree of adequacy by conventional methods. Figure 10 shows a water content profile, also an average of 4 sites in an area. The degree of resolution, consistency and precision is again emphasized. Such data cannot be obtained repetetively and within about one hour by any other method. Figure 11 shows two water content profiles at one site on two days, 25 days apart, during which 50 mm of water was applied. The profile has gained moisture, particularly in the upper part, above 20 cm. The main feature of Figure 11 is the remarkable degree of consistency at the site.

In conclusion, the gamma attenuation method, while neither cheap nor simple, can provide rapid and accurate information on the microprofile of water in the surface layer of soil. This information appears indispensable in interpreting the various forms of microwave signature, and in verifying the adequacy of hydrologic models of soil water disposition. Neither objective can be reached with the usual sampling methods, nor with the neutron scattering method.

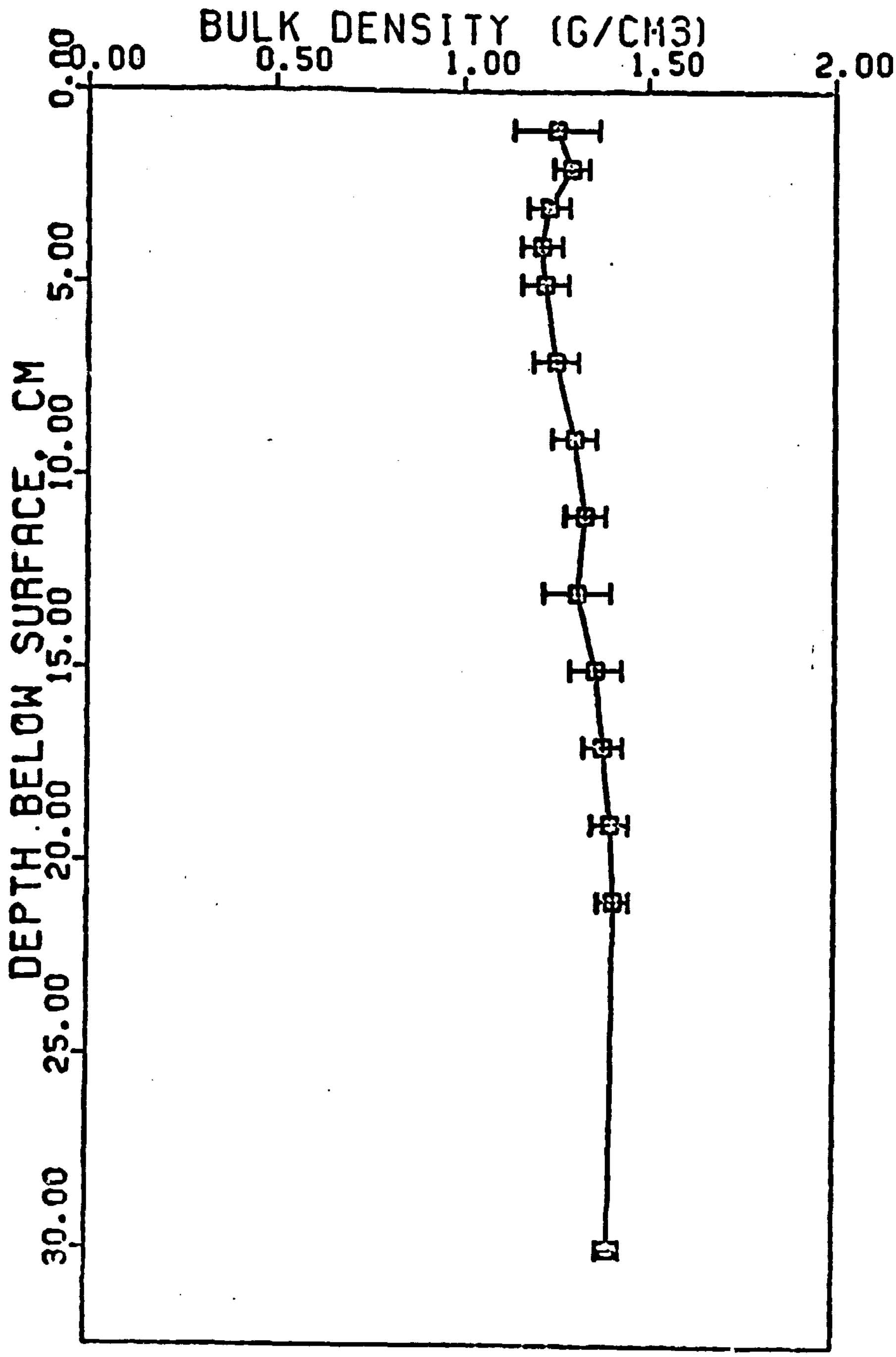


Figure 9. Average dry bulk density of four sites on a bare soil plot as a function of depth. The average bulk density at each depth is ±1 standard deviation.

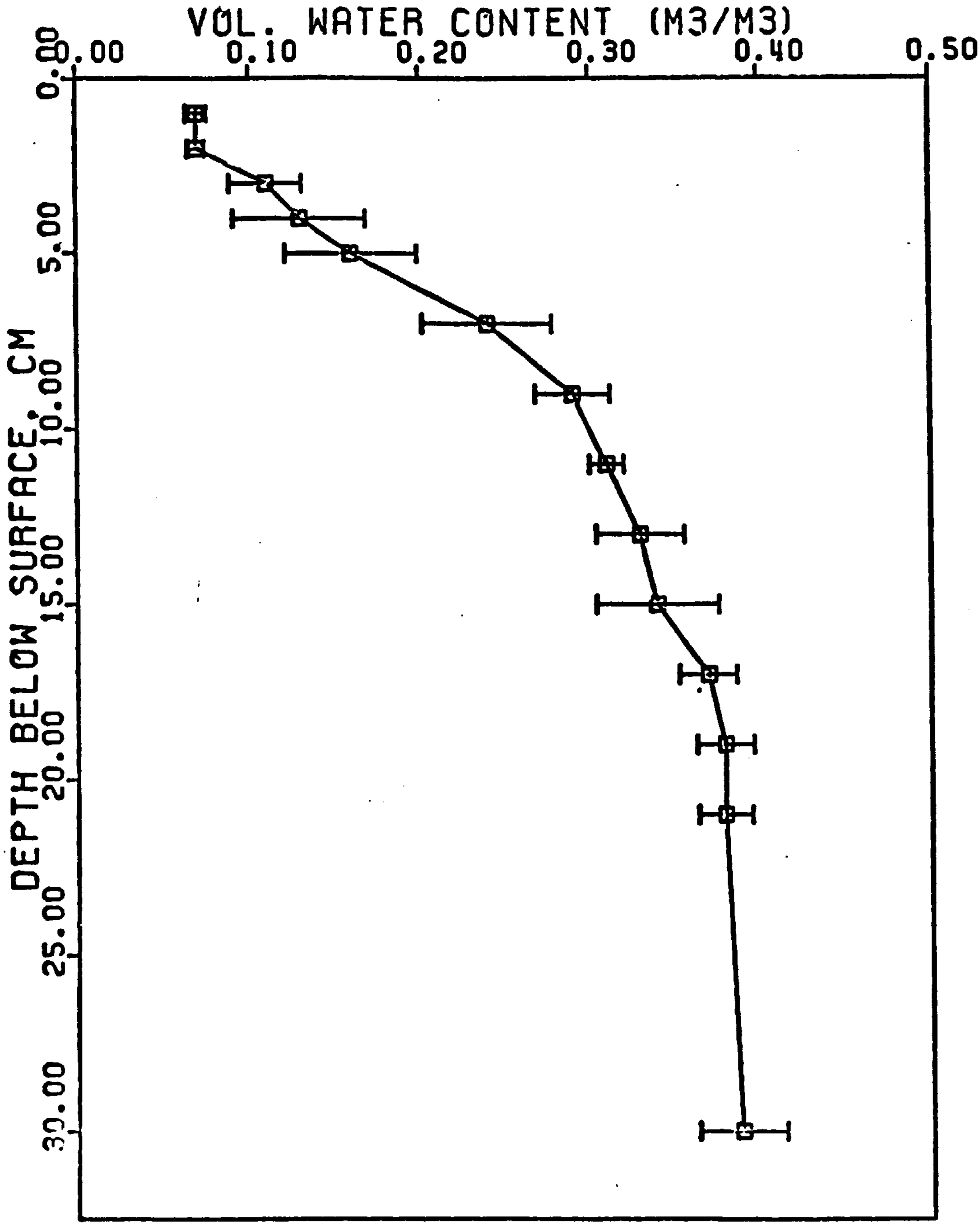


Figure 10. Average volumetric water content of four sites on a bare soil plot, as a function of depth. The average water content at each depth is ±1 standard deviation.

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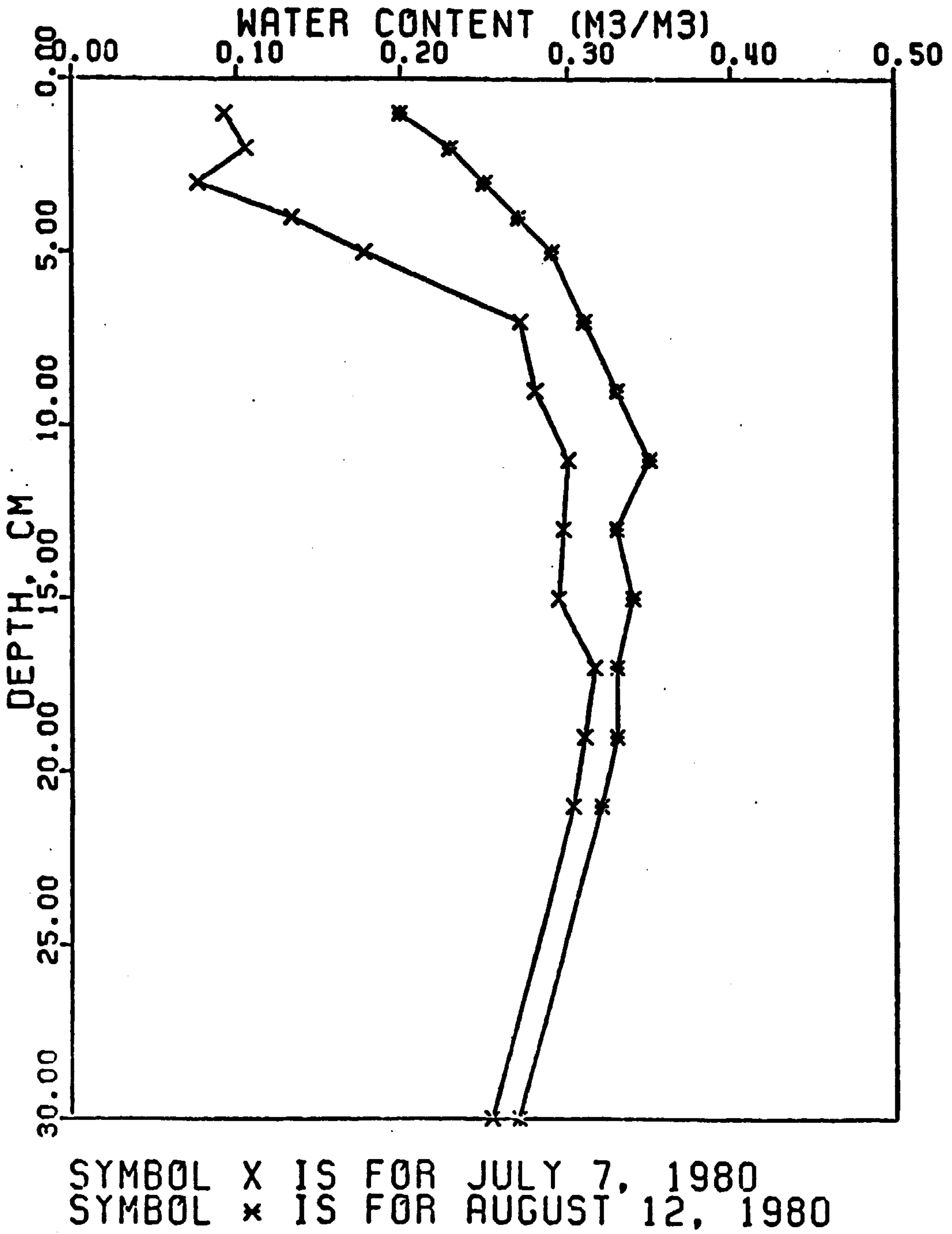


Figure 11. Volumetric water content at one site in a bare field of Norwood silty clay, before and after an irrigation with 50 mm. No rainfall occurred during the period.

Finally, the gamma attenuation method was used to verify the calibration of a Troxler neutron gauge. Earlier, this gauge was calibrated in the usual way, based on careful hand sampling around the access tube. The gauge was calibrated by making simultaneous measurements, with both methods, of moisture profiles at sites selected to give the maximum spread in water content values. The gamma readings were integrated over depth, so as to coincide with the soil layer measured with the neutron gauge, or 20 cm. It was found that the calibration obtained with the gamma method was identical to that found earlier by "direct" means, but that its precision was somewhat better. Calibration of neutron gauges with a gamma probe is easier and faster than by the usual method, but nevertheless a great deal of work.

## Improvement and Adaptation of a Hydro-Energetic Model

The general purpose of contemporary modeling work in the remote sensing of soil moisture and surface temperature is well established, and a number of alternative approaches are on hand. The method aims to predict both the moisture and temperature profiles as a function of time, of meteorological events on an hourly or daily basis, and of soil characteristics. It is based upon earlier work, done at Texas A&M University on the simultaneous dynamics of water and energy in soil and in the atmospheric boundary layer.

The main distinguishing features of this model (CONSERVB) are that it accommodates rainfall and predicts runoff, detention, evaporation, and drainage, as well as the profiles of moisture and temperature. Further, it does not require a functional or curve-fitting expression for the soil properties, it can accomodate any number of distinct soil horizons, and it is written in a concise and easily used simulation language (CSMPIII). A users guide to this program is documented in Technical Report RSC-134 attached to this document.

The current effort is to verify the adequacy of the model in the context of the microwave experiments. There, its principal usefulness lies in interpolating, at any desired time, between or from the periodic ground measurements, using standard meteorological data. Due to unusually wet conditions at the Texas A&M Experimental Farms until June of 1980, no interesting data sets were available, but since that date, good data have been obtained and their evaluation is in progress. A sample is given in Figure 12. An initially dry profile measured on July 2, 1980, and shown in the upper part, was again measured on July 18, 1980 after an application on July 3 and 4 of 330 mm of water with sprinklers, as shown in the lower part. A great deal of water ran off because of an application rate about ten times the estimated intake rate. Also shown is the calculated water content three days after irrigation on July 8 and on July 18 (lower part). The results show, in the latter case, good agreement on a microscale. The upper part is an example of using simulation to calculate a water profile when it is physically impossible to make measurements. On July 8 there was still standing water on the field.

The results are encouraging, but only preliminary. Similar comparisons are in progress on the prediction of surface and soil temperatures as a function of time of day.

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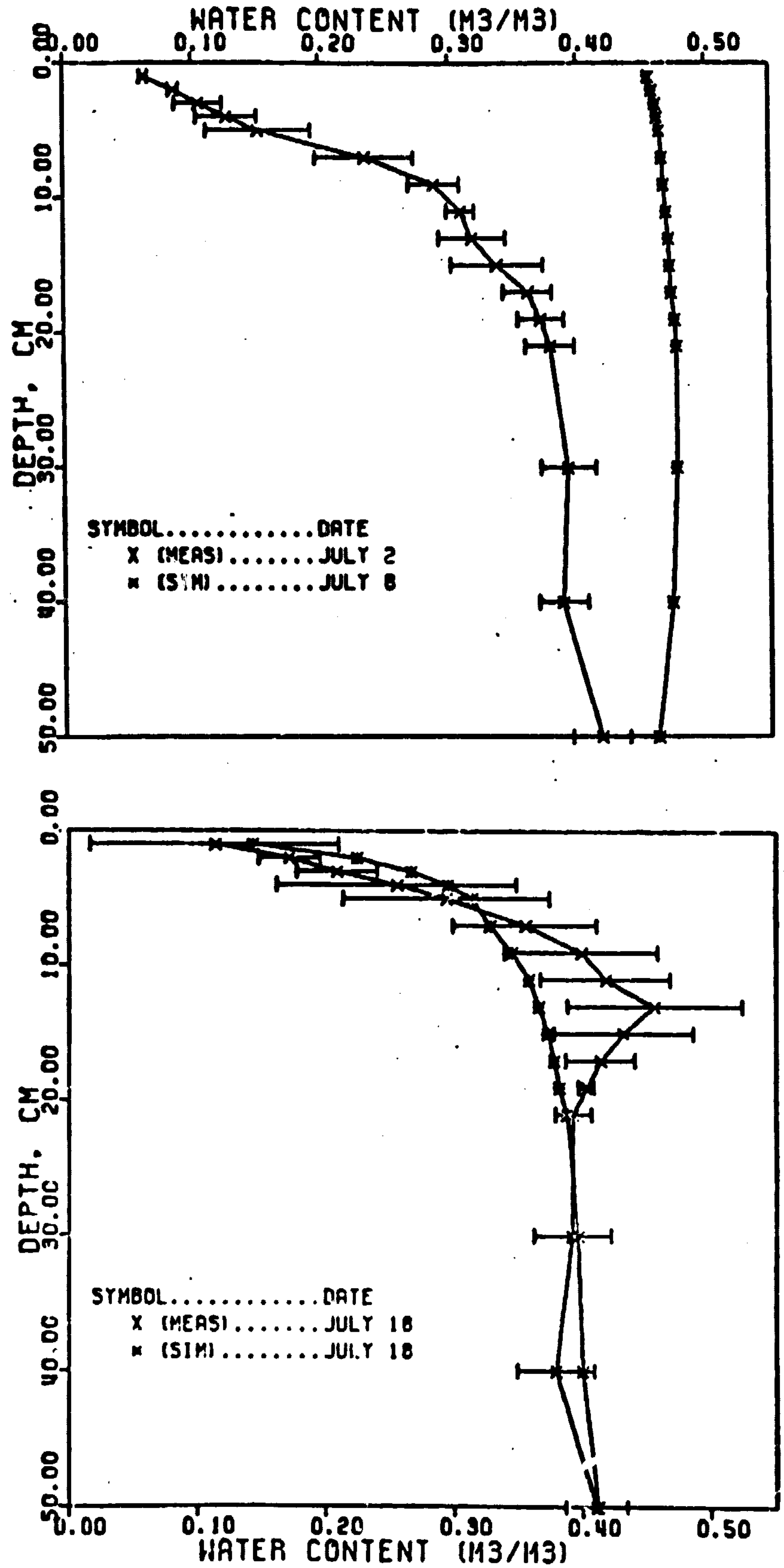


Figure 12. Calculated (*) and measured (X) volumetric water content of a bare Norwood silty clay before irrigation (July 2, upper), immediately after irrigation (July 8, upper) and after redistribution and surface drying (July 18, lower).

## Analysis of Spatial Variability as Relating to Remote Sensing

Unlike the previous two problem areas in which goals and methods are reasonably well defined, there is little to go by from previous work. The obvious fact that the methodology of remote sensing and its verification by ground measurements are both affected by a large natural and non-random variation in soil properties has been conveniently overlooked. Arbitrary decisions have been made in terms of number and patterns of sampling sites, and non-applicable statistical models have been used.

The purpose of this discussion is principally to open a discussion and call attention to a serious lack in our basic knowledge. It is proposed that at least two questions need to be answered. One is: how many ground-truth measurements must be made and in which pattern to be correlated meaningfully with the remotely sensed information that is associated with a specific field of view? Previous studies suggest that if the pattern is random and the individual standard error is large, the required number exceeds the limits of practicality. However, it could well be that with improved measurement accuracy and a non-random sampling grid, a more closely correlated measurement could be made. The second is: What, if any, methodical approach can be worked out to assist in the current effort?

The second question is related to modeling, which is based on the interpretation of soil characteristics that likewise vary in space. How closely must these characteristics be defined and how many sites are needed for characterizing a testing site or a land management unit by modeling its behavior? Sensitivity studies have been made with our model of surface moisture and temperature as well as of water detention and amount of "crop-available" water. It was generally found, by using a scaling approach, that to obtain adequate precision in the calculation of surface properties, it is sufficient to know the order of magnitude of the soil hydraulic conductivity, and to establish the water retention relation to within 0.02 water content on a volume basis.

Both goals are practically attainable. The calculation of run-off and water detention is much more sensitive, as is the estimation of the fraction of "plant-available" water. The former depends directly on infiltrability and the latter on the absolute water content at the "wilting point." However, the first question has not been examined by considering the dynmics of root water uptake. Additional work will be done with a model that simulates crop water use and root proliferation.

## CONTROLLED FIELD EXPERIMENT

In order to acquire soil moisture and meteorologic information necessary to support theoretical and experimental studies described above, a field site was identified and instrumented to acquire soil moisture and meteorologic information year round. The experimental plots and instrumentation are described in detail in Technical Report RSC-114 (AgRISTARS Report SM-T1-04038) that is attached to this document. This work represents the participation of the Agricultural Engineering Department in this research project under the leadership of Co-investigator Dr. J. L. Neiber.

Instrumentation was placed at the field site to acquire solar radiation, net radiation, wind speed, dry bulb temperature, dew point temperature, precipitation, and pan evaporation. These data were automatically recorded every 30 minutes on a Campbell Scientific CR5 digital recorder. In addition to these meteorological parameters, soil moisture was acquired weekly using a neutron probe, a gamma probe, and gravimetrically. Tensiometers were also implanted at one location every cm in depth down to 100 cm, then at 110 cm, 130 cm, and 150 cm. In addition to acquiring these measurements throughout most of the year, a computer model was developed to simulate water balance. The model was based on Ritchey's [7] method of calculating soil evaporation and was evaluated by comparing simulated soil moisture content values to those obtained in the field by use of the neutron probe. Also, a soil water balance was calculated using field data, and compared to potential evaporation as calculated using van Bavel's [8] method and weather data obtained from the experimental test site.

## CONCLUSION

This document summarizes the activities that were on going during the first funding period of NASA Grant NAG5-31. These activities involved theoretical investigations experimental data acquisition to: 1) develop a better understanding of the interaction of electromagnetic energy with soil volumes and the relationship of that interaction to the water content of the soil; 2) develop models of water flow in soil volumes based on known physical processes; and 3) acquire experimental measurements of microwave emission, meteorological parameters, soil characteristics and soil water and soil temperature data simultaneously from controlled experimental test sites for validating theoretical work and developing empirical relationships for utilizing microwave measurements to measure soil moisture. This work is being continued for another funding year commencing February 1981.

# REFERENCES


[1] Newton, R. W., T. A. Howell, J. L. Nieber, and C. H. M. van Bavel, "Microwave Soil Moisture Measurements and Analysis," Final Report RSC-3058, Remote Sensing Center, Texas A&M University, College Station, Texas, May 1980.

[2] Wilheit, T. "Radioactive Transfer in a Plan Stratified Dielectric, "IEEE Transactions on Geoscience Electronics, Vol. GE-16, No. 2, April 1978, pp. 138-143.

[3] Newton, R. W., "Microwave Remote Sensing and its Application to Soil Moisture Detection," Technical Report RSC-81, Remote Sensing Center, Texas A&M University, College Station, TX, January 1977.

[4] Jackson, R. D., "Diurnal Changes in Soil Water Content During Drying" Field Soil Water Regions, R. R. Bruce, editor, Soil Science Society of America, Inc., Madison, Wisconsin, 1973.

[5] Schmugge, T., T. Wilheit, W. Webster, and P. Gloersen, "1976, Remote Sensing of Soil Moisture with Microwave Radiometers - II," NASA Tech. Note TND-8321 (NTIS No. N76-32625) May 1976.

[6] Ulaby, F. T. and P. P. Batlivala, "Optimum Parameters for Mapping Soil Moisture," IEEE Transactions on Geoscience Electronics, Vol. GE-14, No. 2, April 1976, pp. 81-93.

[7] Ritchie, J. T. "Model For Predicters Evaporation From a Row Crop with Incomplete Cover", Water Resources Research, Vol. 8, No. 5, 1972.

[8] van Bavel, C. H. M., "Potential Evaporation: The Combination Concept and Its Experimental Verifications", Water Resources Research, Vol. 2, No. 3, 1966.

## APPENDIX A

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION TEXAS 77843

*College of Agriculture*
*College of Engineering*
*College of Geosciences*
*College of Science*

September 30, 1980



Dr. Thomas Schmugge
Mail Code 913
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Dear Tom:

Attached you will find a list of those accomplishments that have been made on NASA Grant NAG5-31 since its initiation. The statements are organized by the general activity areas that we have been pursuing. The statements are reasonably brief and therefore do not provide much detail. I will be happy to expand on any of the statements if you have questions concerning their meaning.

Two technical reports should be forthcoming soon. One concerns the mathematical description of emission from rough bare soil surfaces and is coauthored by Leung Tsang and myself. The other is essentially Rob Black's masters thesis and contains an analysis of all the aircraft microwave data that we have available to us and a theoretical investigation using the coherent and incoherent emission models into the interpretation of microwave radiometer measurements for soil moisture information. The results of that study have tended to more closely allign my thoughts on the ability to directly measure soil moisture information to depth greater than a few centimeters with what you have believed for some time.

Very truly yours,

Richard Newton
Associate Director

RN/js
cc: Dr. C.H.M. van Bavel
Dr. John Nieber
Dr. Leung Tsang

TEXAS A&M UNIVERSITY
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SUMMARY OF ACCOMPLISHMENTS
NASA Grant NAG5-31



The purpose of this document is to list the accomplishments that have been made at the Remote Sensing Center through the funding of Grant NAG5-31 from the NASA Goddard Space Flight Center. All of the accomplishments listed below are not new scientific findings. A number of them are tasks that had to be completed before additional scientific or experimental work could be continued. As such, they were important accomplishments and warranted individual listing. The brief statements identifying each accomplishment are listed by category. These categories are the Microwave Signature Acquisition System, Data Processing Software Development, Controlled Experiment Implementation, Analysis of Experimentally Acquired Microwave Measurements, Theoretical Analysis of Microwave Emission Theory, and Soil Model Development.

I. Microwave Signature Acquisition System (MSAS)

A. Installed new microprocessor control and data acquisition system

B. Developed and implemented new software operating system

C. Repaired electronic and microwave failures

1. Repaired intermittent multiplexer/line driver failures that caused incorrect information to be transmitted from the microwave receiver on the boom to the controller in the electronics van.

2. Two ports of the microwave switch that routes 1.5 GHz RF energy from the head outputs into the receiver failed. This was temporarily corrected by using unused switch ports. However, this switch should be replaced in the future.

D. Repaired mechanical failures in the electronics data van and gasoline generator engines

E. Eliminated antenna positioning system instabilities

1. Designed new reference pendulum mechanism

2. Redesigned control circuits so that the reference pendulum could be mounted on a fixed part of the truss rather than on the rotatable part of the truss. This minimized effects due to pendulum oscillation.

II. Data Processing Software Development

A. Developed and implemented software for transferring information from the MSAS cassette tapes to nine-track computer compatible tapes.

B. Developed and implemented MSAS data tape file cataloging system

C. Developed and implemented software for generating calibration summaries of measurements contained on raw MSAS data tapes

D. Developed and implemented software for reprocessing raw MSAS measurements into corrected antenna temperatures using the RSC Texas Instruments computer or the Texas A&M Amdahl computer

E. Implemented software for averaging MFMR and scatterometer measurements between field boundary times. This software automatically compensates for antenna beam width and antenna look angle.

III. Controlled Experiment Implementation

A. Implemented bare soil experiment on controlled fields

1. Four surface roughness conditions were measured

2. The soil was irrigated with approximately 8 inches of water and measurements were obtainced as the soil dried down. No rain occurred during the dry down process.

B. Obtained limited vegetated measurements

1. Three fields of sorghum were measured.

2. One field was dry land, the other two fields were irrigated land. However, due to irrigation pump failure, the irrigated sorghum could not be irrigated during the time frame of the experiment. As a result, only relatively dry measurements were obtained on the vegetation.

3. The sorghum was planted in rows, one irrigated field was viewed parallel to the rows, the other irrigated field perpendicular to the rows. The dry land field was viewed parallel to the rows.

C. Ground truth acquired

1. Gravimetric soil samples were obtained at ten locations in each field at depths from the surface down to 21 cm.

2. Soil temperatures were acquired at two locations in each field using thermocouples. Soil temperatures were acquired at four depths within the soil profile.

3. Soil moisture using neutron probes was acquired at six locations within each field down to depths of 1 meter.

4. Gamma ray attenuation probes were used at four locations within each field down to depths of approximately 60 cm.

5. Surface roughness was measured with aluminum grid panels at least two times per field during the experiment.

6. Vegetation height, density, biomass, and percent water content were measured periodically during the experiment. In addition, at harvest the sorghum yield was measured.

7. Soil moisture tension was measured with tensiometers at several depths within the soil for the smooth bare field.

8. Precipitation and other meteorological parameters were measured throughout the experiment.

IV. Analysis of Experimentally Acquired Microwave Measurements

A. Controlled experiment measurements (Since new MSAS measurements have just been obtained; the following points document some of the objectives of its analysis).

1. Passive microwave measurements were obtained at L-,C-, and X-band.

2. The C-band measurements will be used to demonstrate the surface roughness effect at C-band and the soil moisture response at C-band.

3. The L- and X-band measurements will be used to verify previous experimental results demonstrating the effect of surface roughness and soil moisture at L- and X-band.

4. Data is now available for testing the Bausch/Blanchard algorithm for estimating "deep" soil moisture using multifrequency radiometer measurements.

B. Aircraft measurements

1. A data base containing all available airborne passive microwave measruements and assorted ground truth was developed.

2. For the aircraft measurements available, it has been demonstrated that unnormalized antenna temperatures provide a better estimator of soil moisture in the near surface than normalized antenna temperatures.

3. Antenna temperatures normalized by an equivalent soil temperature produces a better soil moisture estimator than antenna temperature normalized by only the near surface soil temperature.

4. Effects due to row orientation have bee identified in aircraft measurements.

5. The effect of vegetation on the soil moisture response is more adverse than the effect previously seen in controlled experimental measurements using the MSAS system.

6. The difference in the vertical and horizontal antenna temperature at off nadir angles might be a useful parameter for the measurement of vegetation effects.

7. Field averages for Colby MFMR and scatterometer measurements are complete for the first two flight dates. Field boundary times have been determined for the second two flight dates, but the microwave date is not yet available.

V. Theoretical Analysis of Microwave Emission Theory

A. Extension of rough surface emission theory

1. Equations that Choudhury, et.al. developed defining emission from rough surfaces in terms of a single parameter were extended to include an additional term.

2. The new development is more complete theoretically and potential provides the capability to describe rough surfaces in terms of a measurable ground truth parameter.

B. Evaluation of coherent and incoherent microwave emission models

1. Both modelling approaches are equivalent in their application to a measurement situation.

2. Care must be exercised in the application of both models to a measurement situation. If the proper care is taken, both models give practically identical results for realistic soil moisture profiles.

3. The coherent model is more costly computationally.

C. Depth of measurement and useful soil moisture parameters

1. It was determined that the air-soil interface modulates significantly the amount of energy escaping through the soil surface from the soil volume.

2. This modulation is controlled to a large extent by the soil moisture within surface layers of approximately a few tenths of a wavelength thick.

3. The modulation inhibits the ability to directly measure soil moisture electromagnetically to depths greater than a few centimeters.

4. The distribution of emitted power intensity with depth is determined primarily by the soil temperature profile. The depths over which this energy originates are typically on the order of one wavelength. Since soil temperature and soil moisture are related, it still remains possible to detect the influence of soil temperature variation and infer soil moisture at depths greater than a few tenths of a wavelength. However, this will require additional investigation. This fact does strengthen the importance of concurrently working microwave emission theory in conjunction with soil water and soil temperature profile models based on soil characteristics and the physics of the soil water interaction.

VI. Soil Water and Soil Temperature Profile Model Development

A. Verification of the van Bavel model

1. Sufficient data was acquired during this summers controlled experiment to complete the verification of the van Bavel soil water/soil temperature profile model.

2. The van Bavel model is being verified by comparing a continuous 18 day run to actual ground truth measurements that were acquired in the experimental test plot.

3. Preliminary results of the gamma probe calibration indicate that the gamma probe is capable of measuring the soil moisture profile to a much greater accuracy than can be done by any other means, including gravimetric sampling.

B. Extension of the soil water/soil temperature profile model to large areas.

1. A sensitivity study has been done to determine the individual sensitivity of the model output to each individual model input. It was determined that average daily parameters are sufficient to provide accurate model predictions.

2. Analyses have been ongoing to extend the validity of the soil water/soil temperature profile model from point solutions to larger area solutions.

# APPENDIX B

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION TEXAS 77843

College of Agriculture
College of Engineering
College of Geosciences
College of Science



December 1, 1980

TO: Ruth Whitman

FROM: R. W. Newton

SUBJECT: NASA Grant NAG 5-31 for Dr. Rango's Peer Review Presentation

A. Major Results (March 2, 1980 - December 31, 1980)

The effort under Grant NAG 5-31 has included five general categories. These categories are listed below with billets indicating the major results of each:

1. Controlled Field Experiment

- Acquired passive microwave measurements at 1.4,4.9, and 10.7 GHz at vertical and horizontal polarization and incident angles from Nadir to 50 degrees.

- Scenes measured consisted of four irrigated bare fields and three vegetated fields (planted in sorghum).

- Acquired most extensive and consistent series of neutron and dual gamma probe soil moisture measurements known to exist.

- Importance of microwave measurements.

    - Measurements were obtained from soil saturation to dry down with no moisture event in betweer. The resulting data provides for the first time direct experimental evidence of the microwave depth of penetration.

    - Provides data to corroberate previous 1.4 GHz and 10.7 GHz results demonstrating soil moisture sensitivity and surface roughness effects.

    - Provides data to demonstrate surface roughness effects and soil moisture sensitivity for first time at 4.9 GHz.

- Importance of Ground Truth Measurements.

  - Provides data to demonstrate the utility of neutron and gamma probes for acquiring suitable ground truth for field experiments.

  - Provides data to thoroughly evaluate soil water hydrologic models.

2. Theoretical Analysis of Microwave Emission

   - Extended rough surface emission theory to provide capability of describing rough surface characteristics with a single field measurable parameter.

   - Comparatively evaluated coherent and noncoherent microwave emission models and determined the techniques of utilizing each so that their results are the same.

   - Determined that soil moisture can be measured directly using remote electromagnetic means only to a depth of a few centimeters due to the modulation effect of the air soil interface transmission coefficient.

3. Analysis of Experimentally Acquired Microwave Measurements

   - Field averages for all of the available radiometric and radar measurements acquired at Colby, Kansas in 1978 have been generated. Soil moisture correlations with confidence limits have been run and are currently being plotted.

   - Analysis of pre-Colby aircraft measurements has been concluded. The results are:

     - Radiometric antenna temperature provides better soil moisture correlation than normalized antenna temperature.

     - Antenna temperature normalized by equivalent soil tmeperature provides a better soil moisture estimator than by normalizing to surface soil temperature.

     - The effect of vegetation on the soil moisture response is more adverse than previously measured with the truck systems.

     - The difference in vertical and horizontal polarizations could provide vegetation information.

4. Soil Water Model Development

   - A detailed analysis of the gamma probe field measurements indicates that the gamma probe provides soil moisture profile information to a better accuracy than can be provided by any other means.

- van Bavel's bare soil, soil water/soil temperature profile model is being verified in detail using the field measurements. Preliminary results indicate that it is verifiable.

- Two techniques have been developed for extending the soil water model from point estimates to area extensive estimates. One is a scaling factor approach, the other is a geo-statistical approach.

5. Microwave Signature Acquisition System (MSAS) Update

- Installed new computer control and data acquisition system.

- Developed new MSAS operating software system.

- Developed all software necessary for processing MSAS measurements to calibrate radiometric antenna temperature.

B. Planned Activities (January 1, 1981 - December 31, 1981)

The effort under the proposed follow-on activities to Grant NAG 5-31 consists of four activity areas. The major organization of the project will remain the same. It will be a cooperative effort between the Remote Sensing Center, the Electrical Engineering Department, the Agriculture Engineering Department, and the Soil and Crop Sciences Department. The major emphasis of the program will be centered around theoretical model and technique development utilizing microwave emission and scattering and soil physics. The major issues are to couple the microwave models to the soil physics models and to develop techniques of extending point measurements to area extensive measurements.

The program is organized in the following manner:

1. Microwave Theory and Techniques (Newton and Tsang(EE Dept))

   Percent Effort - 30%

   - Analytical Development

     - Demonstrate microwave model that characterizes rough surface using field measurable surface roughness parameter.

- Develop model to characterize the emission of vegetation.

- Develop model that accurately describes the permittivity behavior of soil water mixtures.

• Experimental Analysis

- Analyze Colby microwave data set and compare results to previous measurements.

- Utilize controlled MSAS measurements acquired during 1980 to demonstrate rough surface model and to demonstrate depth of penetration understanding developed during 1980.

- Utilize controlled MSAS measurements to demonstrate vegetation model.

• MSAS Measurements

- Execute microwave measurements for irrigated vegetation over the entire growth cycle (wheat and sorghum).

- Execute microwave measurements for irrigated bare soil for sand and loam soils (to determine effect of soil texture).

2. Soil Water/Soil Temperature Profile Model Development (van Bavel, Soil and Crop Sciences Department)

   Percent Effort - 15%

   • Complete detailed validation of soil water profile model using field measurements.

   • Initiate development of soil water profile model that includes a vegetation cover.

   • Develop technique of extending point models to area extensive application.

   • Assist in the design of field experiments.

3. Experimental Field Site Development/Maintenance/Data Acquisition (Nieber, Agricultural Engineering Department)

   Percent Effort - 15%

   • Implement, maintain, and operate continuing meteorological field measurement facility.

   • Acquire neutron and gamma probe soil moisture measurements during experiments.

   • Assist in instrumenting and maintaining field sites.

4. Active Microwave Hardware Development (Blanchard, Remote Sensing and Electrical Engineering Department)

Percent Effort - 40%

- Design L, C, and X-band dual polarized truck mounted radar system (these frequencies match the radiometer frequencies).
- Implement and test radar hardware (actually construct two sets of hardware - one to be delivered to Goddard for mounting on their truck system).
- Implement boom truck and electronics data van and mount radar (trucks to be purchased by TAMU).